Planetary Spectra as Calibration References

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The spectra of solar-system objects have been viewed as a means to establish a calibration system that bridges the gap between bright infrared stars and strong radio sources. Traditionally the planet Mars has been used, but there are several problems with it that need to be overcome. Planetary properties, such as albedo, specific heat and altitude, that are required to determine the thermal output from the surface, are not all known for all relevant latitudes. An appropriate model for surface roughness must bridge the transition from (i) the infrared, where the emissivity is close to unity to (ii) longer wavelengths, where the surface behaves more like a smooth dielectric surface. Transient phenomena, such as dust storms, may be unmodeled. In the far infrared, the influence of many rotational water vapor lines must be taken into account, particularly by high-resolution spectrometers. Finally, Mars is too bright to be accommodated by the linear sensitivity range of some detectors.

Griffin and Orton (1993. Icarus 105, 537) suggested Uranus as an alternative calibrator. It is not very bright. It has a very deep atmosphere with, little detectable longitudinal variability. It is currently almost pole-on, minimizing the periodic nature of any longitudinal variability that may exist. On the other hand, Uranus' thermal properties are not as well characterized as those of Mars. In fact, there are ultimately two sources of calibration for Uranus' middle- to far-infrared spectrum. One is Mars itself for wavelengths longer than 50 μm; the other is an internal instrument calibration for the Voyager IRIS experiment between $\sim$30 and 50 μ. Unfortunately, the spectral ranges for both of these do not overlap a short-wavelength region (17 - 22 μm) that is calibrated against a stellar standard. Thus, interpolation or extrapolation of these results is accomplished using a best-fit model, raising the spectre that the specific properties assumed in that model may influence the derivation of those similar properties in other atmospheres. An example of this is determining the He/H_2 ratio using Neptune's spectrum that was calibrated using a model for Uranus with a similar mixing ratio that was assumed as a part of the model. Furthermore, just as for Mars, there may be absorption lines in Uranus' spectrum from as yet unknown constituents.

Despite the shortcomings of both planets, work done by the ISO LWS team, summarized by Sunil Sidher at this meeting, shows a good correlation between the observed *vs* modeled radiances of Uranus compared with Mars. Thus, it marks the beginning of a solar-system-based calibration system. A goal of such a calibration system is to be capable of deriving spectral flux values that are good to 2–3% or better on an absolute scale, and 1% or better on a relative scale, similar to stellar calibration systems.

This calibration system can be improved with the addition of data referenced to independent sources, such as spacecraft calibrations (as was the case with Uranus) or a stellar calibration system. Alternative calibration sources might be investigated, such as bright minor planets that have well-constrained models of thermophysical surface properties. For shorter wavelengths, Jupiter's outermost Galilean satellite, Callisto, could also fulfill this role, as discussed by Thomas Mueller at this meeting. For instruments with large fields of view that are capable of observing bright objects, Jupiter itself can serve as a standard, as its spectrum is being characterized by the Cassini CIRS experiment from 16 to 500 μm, using an internal calibration scheme. However, unpredictable meteorological variations must be included in the uncertainty of such a calibration. Finally, it is unfortunate that Venus is inside the solar avoidance region for most spacecraft observations. Its deep atmosphere has only small spatial variations in temperature, and these have largely been characterized very well by a variety of remote and *in situ* investigations. Furthermore, its far-infrared through submillimeter spectrum is governed by a predictable continuum arising from carbon dioxide collision-induced opacity.

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